



LCD In-Cell Touch

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<begin>About NextWindow

❑ NextWindow

- ◆ Develops & manufactures optical touchscreens
- ◆ Currently focused on two touch-screen markets
 - Windows-7 consumer monitors and all-in-one computers
 - Large-format display applications such as interactive digital signage
- ◆ Global presence
 - HQ in New Zealand; offices in USA, Taiwan and Singapore
 - Manufacturing in China, Thailand and Malaysia
 - 100 employees, 45 in engineering
- ◆ Brief history
 - 2000: Founded by CTO and private investors
 - 2003: First product to market (optical touch for large displays)
 - 2005: Entered USA market
 - 2006: First major volume contract signed (HP TouchSmart AiO)
 - 2008: Entered Taiwan market with ODM focus
 - 2009: Engaged with many PC OEMs & ODMs on Win-7 products

Agenda

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[44] = Total number of content slides



Introduction

Source: TMD

Three Different Physical Integration Methods Used In LCD “In-Cell” Touch

Term	Integration Method
In-Cell	<p>Touch sensor is <i>physically inside the LCD cell</i></p> <p>Touch sensor can be:</p> <ul style="list-style-type: none">• Light-sensing elements (light-sensing)• Micro-switches (voltage-sensing)• Capacitive electrodes (charge-sensing)
On-Cell	<p>Touch sensor is an X-Y array of ITO conductors <i>on the top or bottom surface of the color filter substrate</i></p> <ul style="list-style-type: none">• Capacitive-only ⁽¹⁾
Out-Cell	<p>Standard touchscreen <i>laminated directly on top of the LCD</i> during manufacture</p> <ul style="list-style-type: none">• Key difference: An additional piece of glass is required• Typically only projected capacitive or analog resistive• New term coined by AUO – <i>Since this term hasn't entered common usage yet, some LCD manufacturers still refer to this configuration as on-cell</i> ⁽²⁾

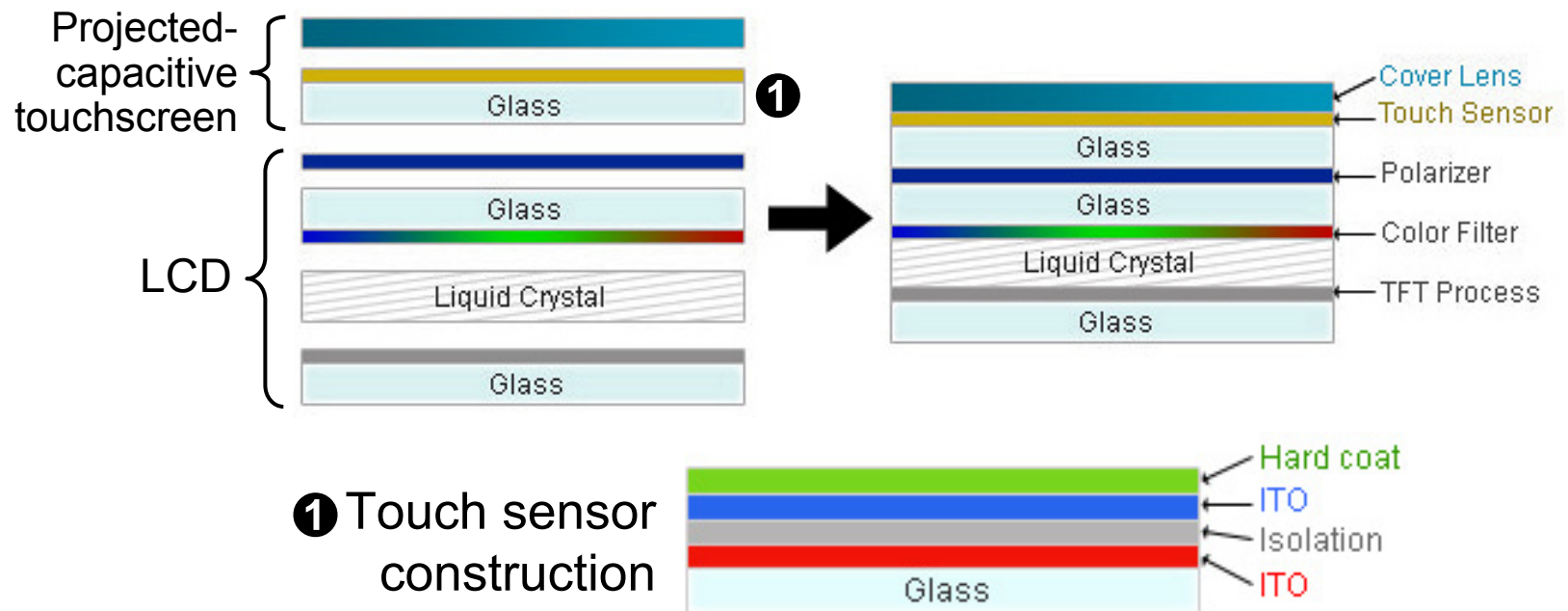
(1) CMO & AUO persist in labeling their on-cell capacitive (on top of the color filter glass) as “in-cell” capacitive.

(2) LGD's 6.4-inch “on-cell capacitive” at SID 2009 was actually a laminated cover-glass with ITO patterning on the under-side (out-cell).

Out-Cell...1

❑ Projected-capacitive or resistive touchscreen is laminated onto LCD

- ◆ Lower-cost than 3rd party, so likely to become a general trend
- ◆ Well-known touch-screen suppliers are working with LCD mfgs



Source: Cando

Out-Cell...2

Touch Technology	Difficulty of Out-Cell Integration
Analog & Digital Resistive	None
Projected Capacitive	None
Optical	Cameras & reflectors on top of LCD cell; no cover glass is required
Traditional Infrared	PCB around entire screen; no cover glass is required
Surface Capacitive	Metal LCD frame cannot contact touchscreen & must be grounded
Surface Acoustic Wave	Reflectors and transducers on touchscreen glass must be protected
Waveguide Infrared (RPO)	Waveguides & sensors on top of cover glass; LED(s) on edge of cover glass
Acoustic Pulse Recognition (Elo)	Touchscreen mounting is critical
Dispersive Signal Technology (3M)	Touchscreen mounting is critical
Force-Sensing	Touchscreen mounting is critical
Vision-Based	Not applicable (projection only)

Three Different Technologies Used In LCD In-Cell & On-Cell Touch

❑ Light-sensing or “optical”

- ◆ Addition of a photo-sensing element into some or all pixels
- ◆ Works with finger, stylus, light-pen or laser pointer; also works as a scanner; cover glass is OK

❑ Voltage-sensing or “switch-sensing”

- ◆ Addition of micro-switches for X & Y into some or all pixels
- ◆ Works with finger or stylus, within damage limits of LCD
- ◆ No cover-glass

❑ Charge-sensing or “capacitive-sensing”

- ◆ Addition of electrodes in-cell or on-cell for capacitive sensing
- ◆ In-cell = works with finger or stylus, within damage limits of LCD; no cover-glass
- ◆ On-cell = works with finger-only; cover-glass is OK

Who's Working On What (January 2010)

LCD Manufacturer	Light-Sensing	Voltage-Sensing	Charge-Sensing (in-cell or on-cell)	Hybrid Charge & Voltage (in-cell)
AUO	✓	✓	✓	✓
Chi Mei Innolux			✓	
CPT			✓	
HannStar	✓			
LG Display	✓	✓	✓	
NEC			✓	
Samsung	✓	✓	✓	✓
Seiko-Epson			✓	
Sharp	✓		✓	
Sony	✓			
TMD	✓			

 = Primary  = Secondary

Bold = Most significant efforts

Theoretical Advantages of In-Cell

- ❑ Minimal or no added size, thickness or weight, so no effect on the end product's industrial design
- ❑ Unlimited multi-touch functionality (controller-dependent)
- ❑ Conceptually very high touch-performance
 - ◆ Low parallax error (assuming no cover-glass)
 - ◆ Very accurate and linear touch-point data (fixed pixel matrix)
 - ◆ Potentially higher resolution than the LCD through inter-pixel interpolation
- ❑ Much lower cost for the touch function, since changes in an LCD's manufacturing cost should be minimal

In reality, all of these advantages have turned out to be compromised to some degree



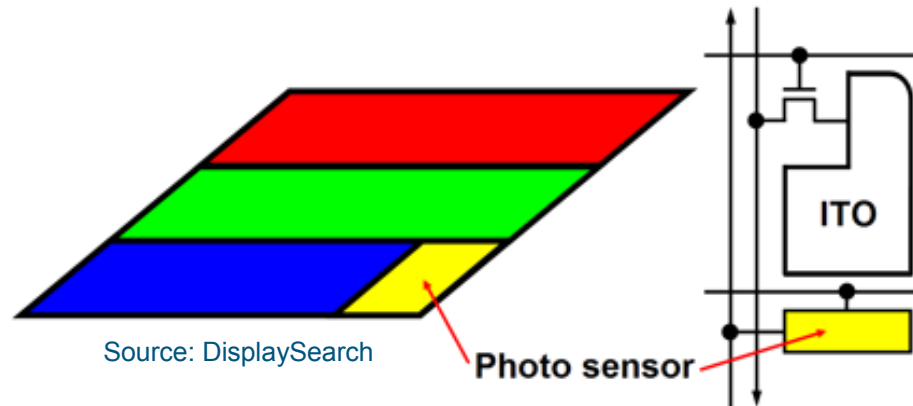
Source: Flickr

Light-Sensing

Light-Sensing...1

□ Principle

- ◆ Photo-sensor in each pixel or group of pixels sees shadow of finger in bright light or reflection of backlight on finger in dim light



□ Variations

- ◆ Number of pixels per sensing element

□ Size range

- ◆ 3" to 20" (LTPS or CG)
- ◆ Unlimited (a-Si)

Light-Sensing...2

□ History

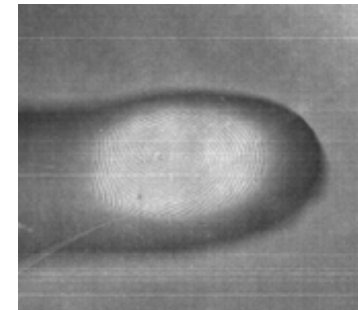
- ◆ TMD was first to announce the concept on 4/03 as a product they intended to commercialize
 - Also first to announce auto-switching between shadow & reflection
- ◆ Sharp announced the same concept on 8/07
 - Sharp has one netbook product in current production
- ◆ Samsung announced the same concept in a 7" display at IMID in 8/07
 - Samsung has two camera products in current production
- ◆ AUO announced the same concept in a 4.3" mobile display at FPD/International on 10/07
 - AUO has three LCDs in current production
- ◆ LG.Philips announced the same concept in an automotive LCD at FPD/International on 10/07

Light-Sensing...3

□ Advantages

- ◆ Integration, size, thickness, weight, ID
- ◆ Unlimited multi-touch (controller-dependent)
- ◆ Conceptually high performance
 - Low parallax error (assuming no cover glass)
 - Very accurate & linear touch-point data
 - Potentially higher resolution than LCD
- ◆ Lower manufacturing cost
- ◆ Can work as a scanner
- ◆ Capable of detecting the difference between hover & touch
 - Problematic in low ambient

**All the
theoretical
advantages
of in-cell**



Sample captured image on
2.6" VGA (300 ppi)

Source: Sharp

Light-Sensing...4

❑ Disadvantages

- ◆ Touching a black image doesn't work in low ambient light
- ◆ Using a photo-sensor to reliably detect touch over the range of full sunlight to total darkness is very difficult
 - Touching object shadow vs. proximate object shadow
 - Reflection from backlight vs. reflection from external light source
- ◆ Putting a light-sensor in every pixel consumes too much of the aperture (reducing efficiency) and requires too much processing power
 - But using one light-sensing element for each X pixels (e.g., 9) reduces scanning resolution and reduces quality of digital ink
- ◆ The LCD's display function and the touch function tend to interfere with each other ("severe EMI problems" - Sharp)
 - Speeding up the touch function makes it worse

Light-Sensing...5

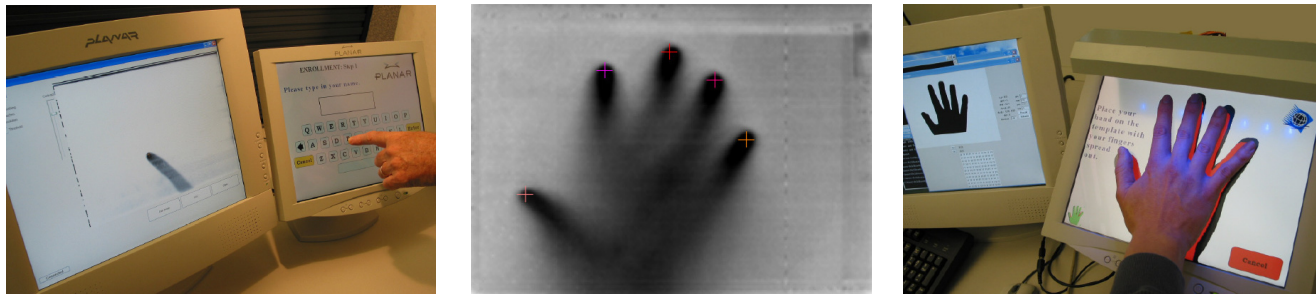
❏ **Disadvantages** (*continued*)

- ◆ The amount of processing power needed to operate the touch function results in high power consumption
 - Analog-to-digital conversion
 - Position determination
 - Image processing
 - Gesture/motion recognition (in OS other than Windows 7)
- ◆ A cover-glass is desirable to protect the LCD, but a cover-glass reduces touch sensitivity due to the spacing between the finger and the photo-sensing element
 - Optical bonding helps (at additional cost & lower yield)
 - Harder LCD top-polarizer is the best solution to this problem

Light-Sensing...6

❑ Potential solutions to the “can’t touch black” problem

- ◆ Add an IR light source into the backlight and make the light-sensing elements IR-sensitive (Sharp’s solution)
 - IR goes through the LCD and reflects off the finger
 - But this significantly increases power consumption
- ◆ Add IR edge-lighting on a cover glass and use FTIR
 - Planar created IP on this idea⁽¹⁾ in 2004-2007, then sold it to an unidentified buyer in 2009, who may not be willing to license it



Source: Planar

(1) ACM: “Optical Sensors Embedded Within AMLCD Panel: Design and Applications”,
Adi Abileah & Patrick Green, Planar Systems (8/4/2007)

Light-Sensing...7

□ Applications

Electrophoretic

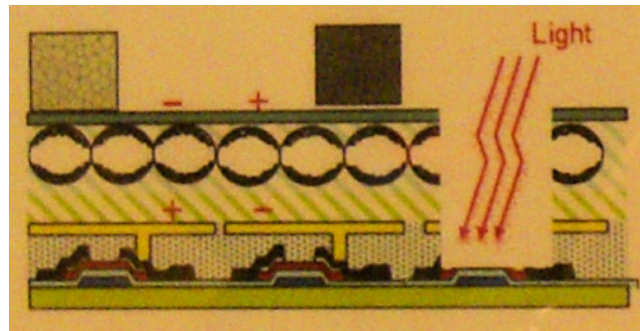
- ◆ Mobile devices are clearly the initial target
- ◆ LGD & e-Ink showed an e-book reader with in-cell light-sensing touch at SID 2009
 - But it would suffer from the same “can’t touch black” problem, with no easy fix
- ◆ AUO & SiPix announced a similar concept at Display Taiwan 2009



Source: Sharp



Source: AUO



Source: LGD

Light-Sensing...8

First use of in-cell light-sensing touch in a commercial product

❑ Sharp's PC-NJ70A netbook (5/09)

- ◆ Optical in-cell touch in 4" CG-silicon 854x480 touchpad LCD (245 dpi)

- 1 sensor per 9 pixels
- LED backlight
- Stylus & 2-finger multi-touch
- Scanning (shape recognition)
- Touch surface = ??
- Japan-only; \$815

◆ Problems

- Need IR from backlight
- **S L O W** (25% of typical touchpad speed)
- Short battery life

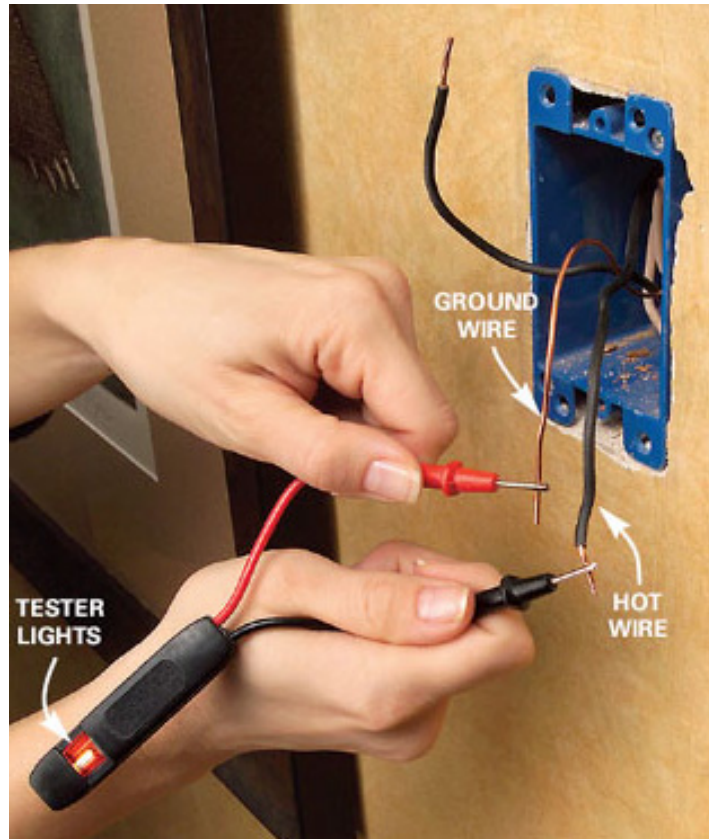


Source: Sharp

Light-Sensing...9



Source: AkihabaraNews.com



Source: The Family Handyman

Voltage-Sensing

Voltage-Sensing...1

❑ Principle

- ✦ Pressing LCD surface closes micro-switches in each pixel
- ✦ Similar principle as emerging “digital resistive” touch technology

❑ Size range

- ✦ 3” to 26” (AUO’s stated maximum)
- ✦ Limited by RC-loading of (and space for) connecting traces

❑ Controller

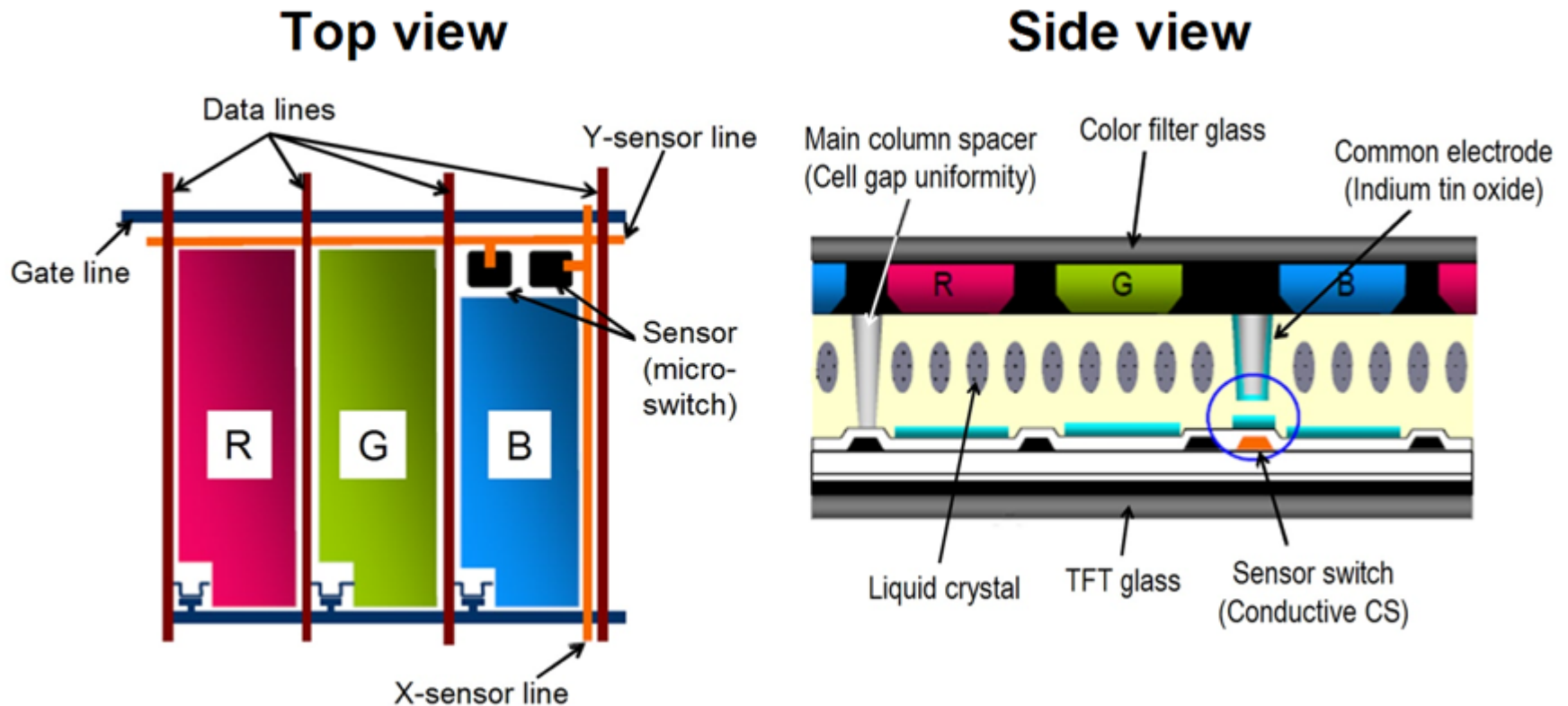
- ✦ Needs “isolated drive & scan”, like Stantum’s digital resistive
 - There may be significant IP restrictions in this area
- ✦ Relative simplicity potentially allows integration into LCD driver

❑ Applications

- ✦ No LCD manufacturer has announced any in-cell voltage-sensing LCD products yet, but mobile would be a logical target

Voltage-Sensing...2

- ❑ Samsung's design (AUO's is very similar)



Source: Samsung

Voltage-Sensing...3

❑ Advantages

- ◆ All the theoretical advantages of in-cell...
- ◆ Simplest controller of the three in-cell technologies
- ◆ Independent of ambient and back-lighting
- ◆ One sensor per pixel would be optimum for use with a stylus, since sub-pixel resolution can be achieved by inter-pixel interpolation

Voltage-Sensing...4

❑ Disadvantages

- ◆ Voltage-sensing won't work with a cover glass, so the LCD can easily be damaged
 - AUO's 2008 spec is only 100K touches at <40 grams! – although it's unclear if it's limited by LCD surface damage or ITO cracking
 - ✓ Typical resistive touchscreen spec is 1M touches (4-wire) or 30M touches (5-wire) at ~80 grams
 - Harder LCD top-polarizer is the best solution to this problem, but until there's more demand for touch, it's chicken-and-egg
- ◆ Liquid-crystal pooling can be visually distracting
 - Changing cell-spacer structure or moving to IPS are possible fixes
- ◆ Reduction in aperture causes reduces efficiency
- ◆ Finite (non-zero) activation force, which can make multi-touch gestures more difficult to perform than with capacitive
- ◆ “Unstable contact” at the edge of the screen (LGD)



Source: Brookhaven National Laboratory

Charge-Sensing

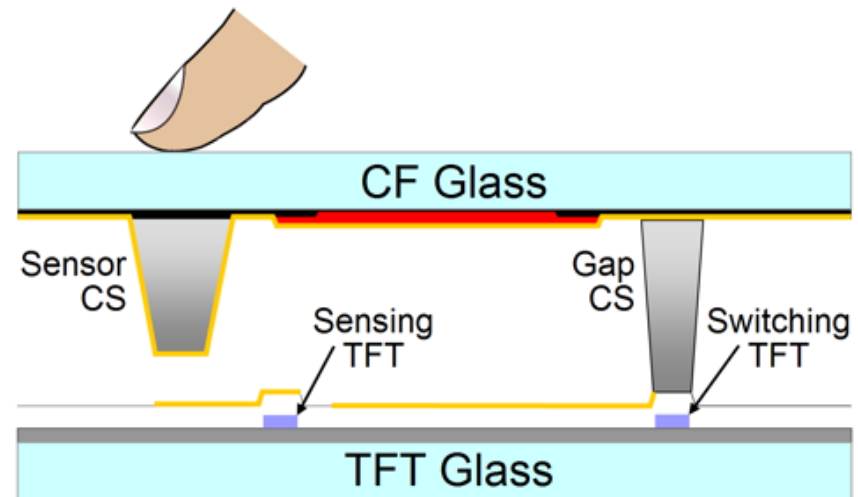
Charge-Sensing...1 (In-Cell)

❑ In-cell

- ◆ Capacitive-sensing ITO electrodes added inside the LCD cell (sometimes called “pressed capacitive”)

❑ Principle

- ◆ Pressing the LCD changes the dielectric constant of the liquid crystal, which changes the capacitance between the electrodes
- ◆ Requires touching the LCD surface (low durability)
- ◆ Works with finger or stylus; human body capacitance isn't a factor

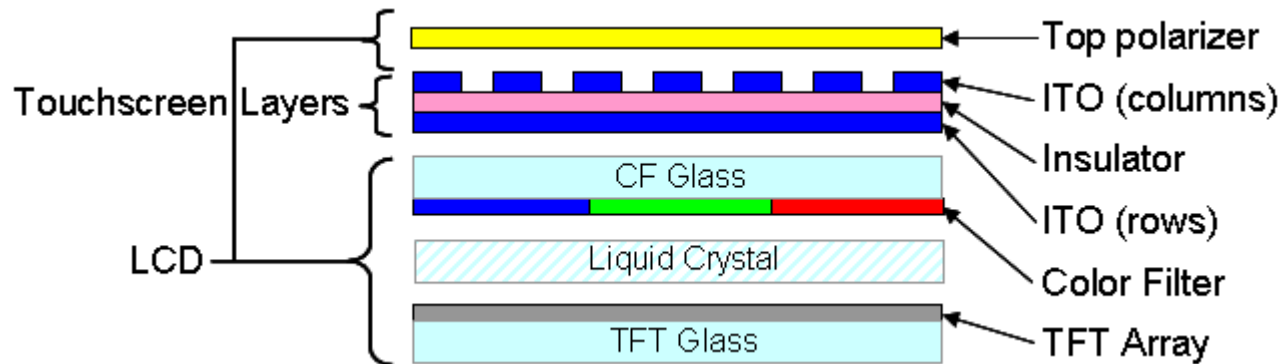


Source: LG Display

Charge-Sensing...2 (On-Cell)

❑ On-cell

- ◆ Projected-capacitive X-Y electrode array added on top of the color filter glass, under the top polarizer



Source: Author

❑ Principle

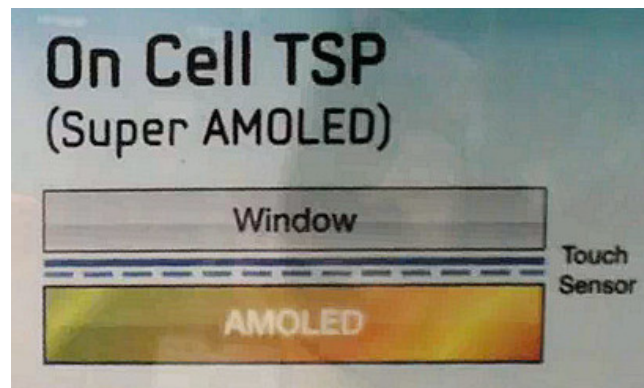
- ◆ Same as standard projected-capacitive
- ◆ Works only with finger; human body capacitance changes mutual capacitance between electrodes
- ◆ Cover-glass (0.5 mm) can be added on top of polarizer to protect LCD surface

Charge-Sensing...3 (On-Cell Touch Isn't Just for LCDs)

- ❑ **Samsung S8500 Wave mobile phone with Super OLED on-cell charge-sensing touch (2/10)**
 - ◆ 3.3-inch 800x480 (283 ppi) AMOLED
 - ◆ “Super OLED” is Samsung’s (poor) branding for on-cell touch
 - ◆ Sunlight readable
 - AR coating & no touchscreen overlay



Source: Samsung



“Window” here refers to the “cover lens” that’s laminated on top of the display

Source: Samsung booth graphic at Mobile World Congress 2010

Charge-Sensing...4

❑ Size range

- ◆ 3" to 24" (limited by RC-loading of traces and by space required)

❑ Applications

- ◆ Handheld mobile devices are the initial target, followed by netbooks and notebooks

❑ Advantages (in-cell & on-cell)

- ◆ All the theoretical advantages of in-cell...
- ◆ Sensing touch by measuring capacitance is well understood
- ◆ Independent of ambient and back-lighting
- ◆ Cover-glass can be added to protect the LCD surface (on-cell)
- ◆ CF fabs can be modified to support manufacturing (on-cell)



Source: AUO

Charge-Sensing...5

❑ Disadvantages (in-cell & on-cell)

- ✦ All forms of capacitive sensing are subject to electrical noise; successful integration into the LCD can be very difficult, especially as the LCD size increases or with noisy LCDs
- ✦ Significant processing power is required in the controller in order to achieve acceptable performance
 - In-cell controller is relatively unique due to high level of integration with LCD, and there's no interface standard
 - On-cell controller can be similar to standard pro-cap controller; on-cell (pro-cap) algorithms are more well-developed than in-cell
- ✦ Lower touch resolution than light-sensing or voltage-sensing
 - Less important with on-cell due to finger resolution

Charge-Sensing...6

❑ Disadvantages (in-cell & on-cell) (*continued*)

- ◆ Smaller aperture ratio (in-cell) or X-Y electrode array (on-cell) reduces transmissivity
- ◆ Liquid-crystal pooling with in-cell can be visually distracting
 - Using a cover-glass with on-cell reduces it but doesn't eliminate it
- ◆ In-cell charge-sensing won't work with a cover glass, so the LCD can easily be damaged
- ◆ Lack of stylus support with on-cell limits some applications
 - Handwriting Kanji characters with a stylus on a mobile phone is very popular in Asia

Charge-Sensing...7

❑ AUO's 3.5", 4.3" & 5" charge-sensing LCDs (10/07)

- ◆ They're on-cell, even though AUO calls them in-cell!
- ◆ Multi-touch = 2 points only
- ◆ Touch interface = I²C + unique interrupt structure
- ◆ No announced design wins

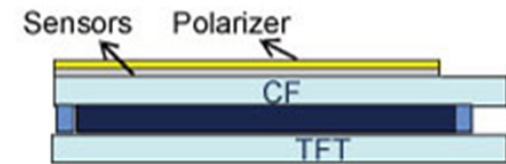


Figure 1. AUO In-Cell Multi-Touch Panel–Charge Sensing
Module thickness: 2 glasses + backlight

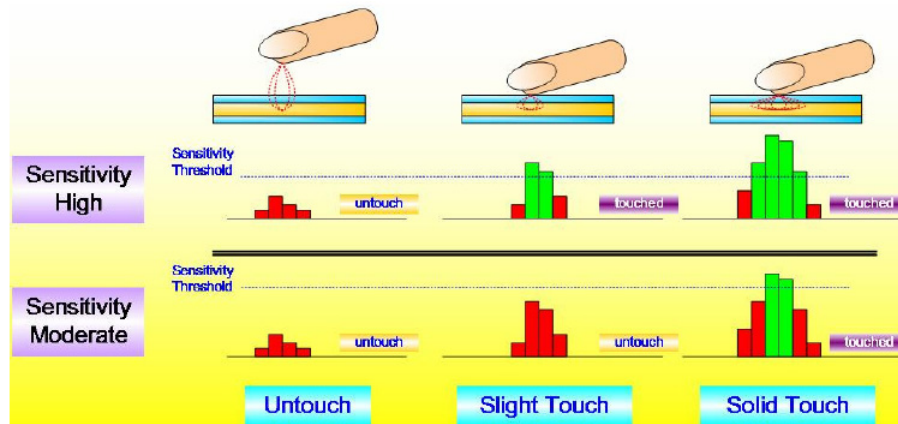


Figure 7.6. Sensitivity Adjustment

Source: AUO

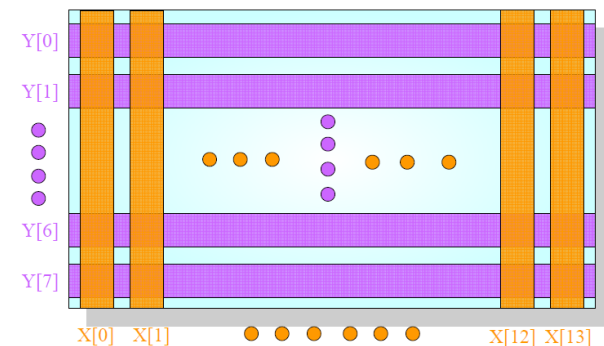
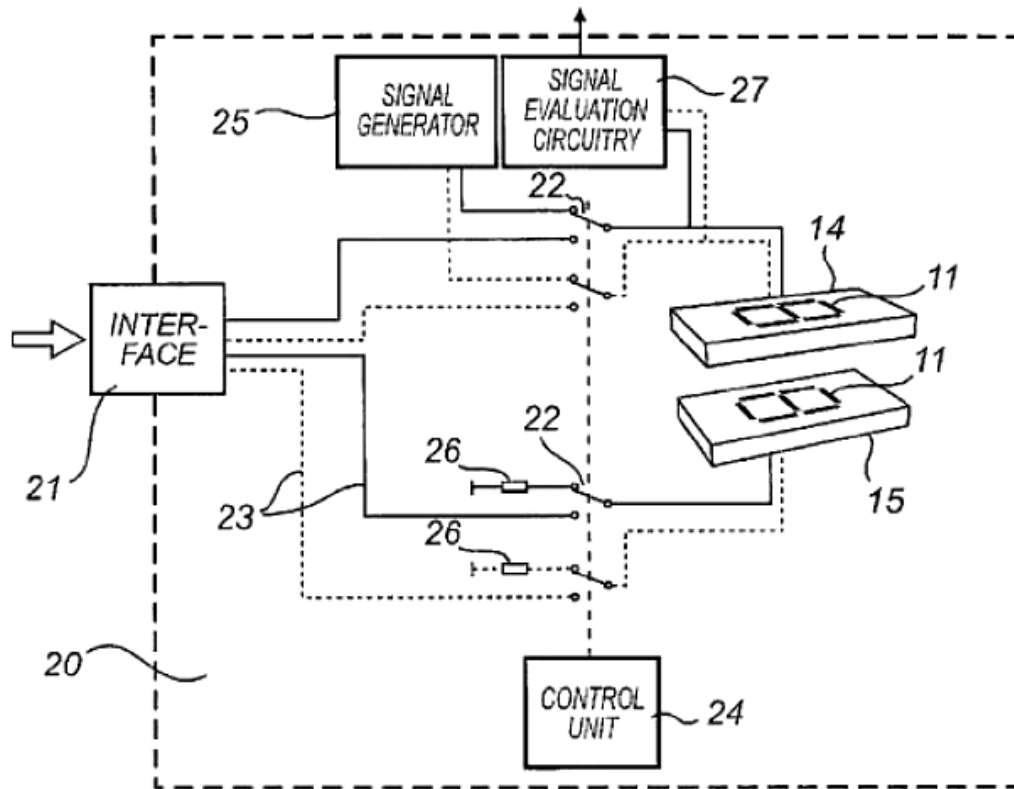


Figure 7.4. Reference of channel location diagram

Charge-Sensing...8

❑ A possible variant of in-cell: Integritouch (Sweden)

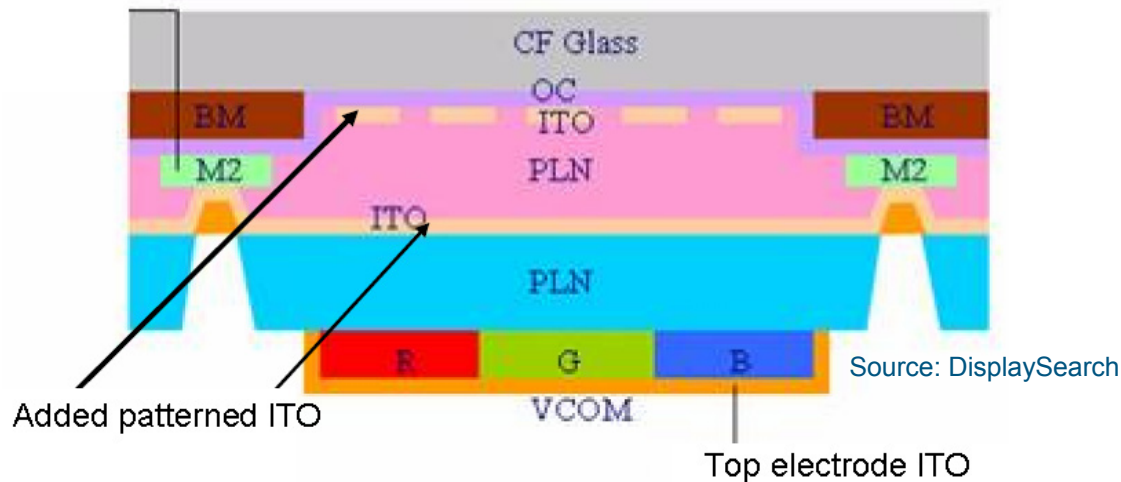


- ◆ Integritouch's patented method of switching the LCD's existing internal electrodes to become self-capacitive touch-screen electrodes during the refresh cycle
- ◆ Patent WO **2005/036510**
- ◆ No real traction to date
 - Licensing is uncommon in LCD industry
 - There may not be enough significant advantages

Charge-Sensing...9

❑ A possible variant of on-cell

- ◆ Projected-capacitive X-Y electrode array added underneath the color filter glass, between the glass and the color filter

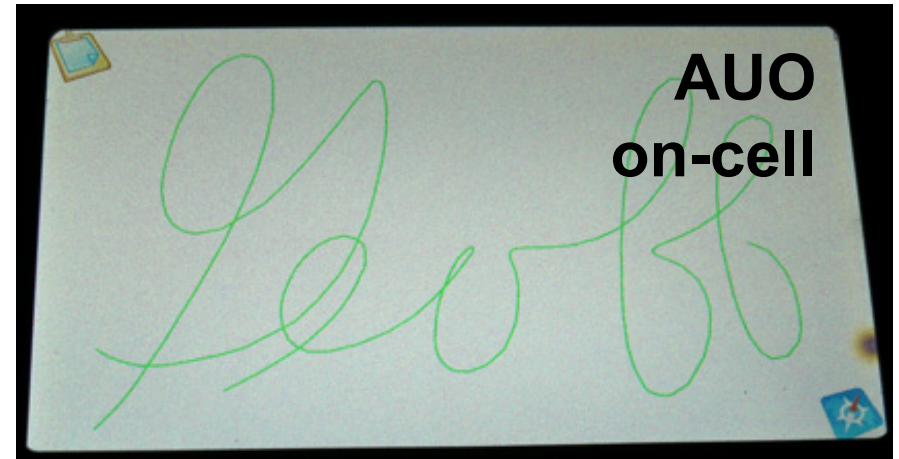
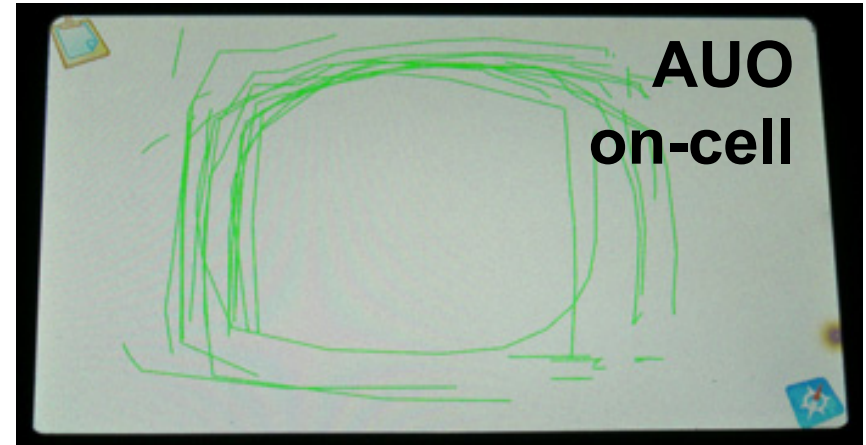
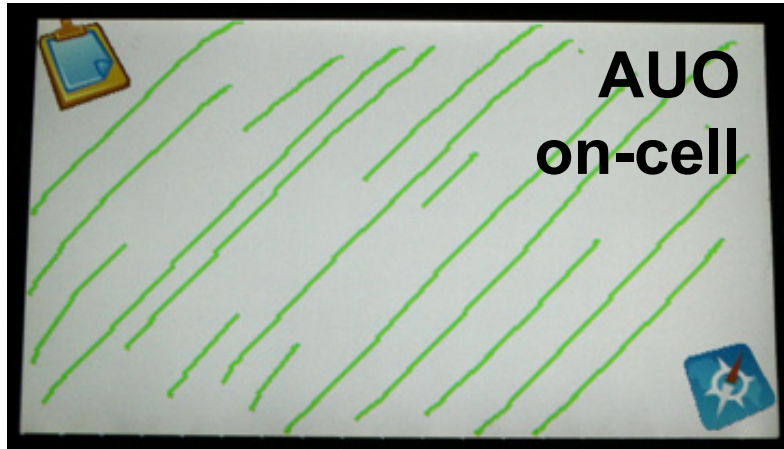


- ◆ Unclear if anyone is actually doing this
- ◆ Works only with finger
- ◆ Adding a cover-glass (0.5 mm) on top of polarizer may reduce the sensitivity too much

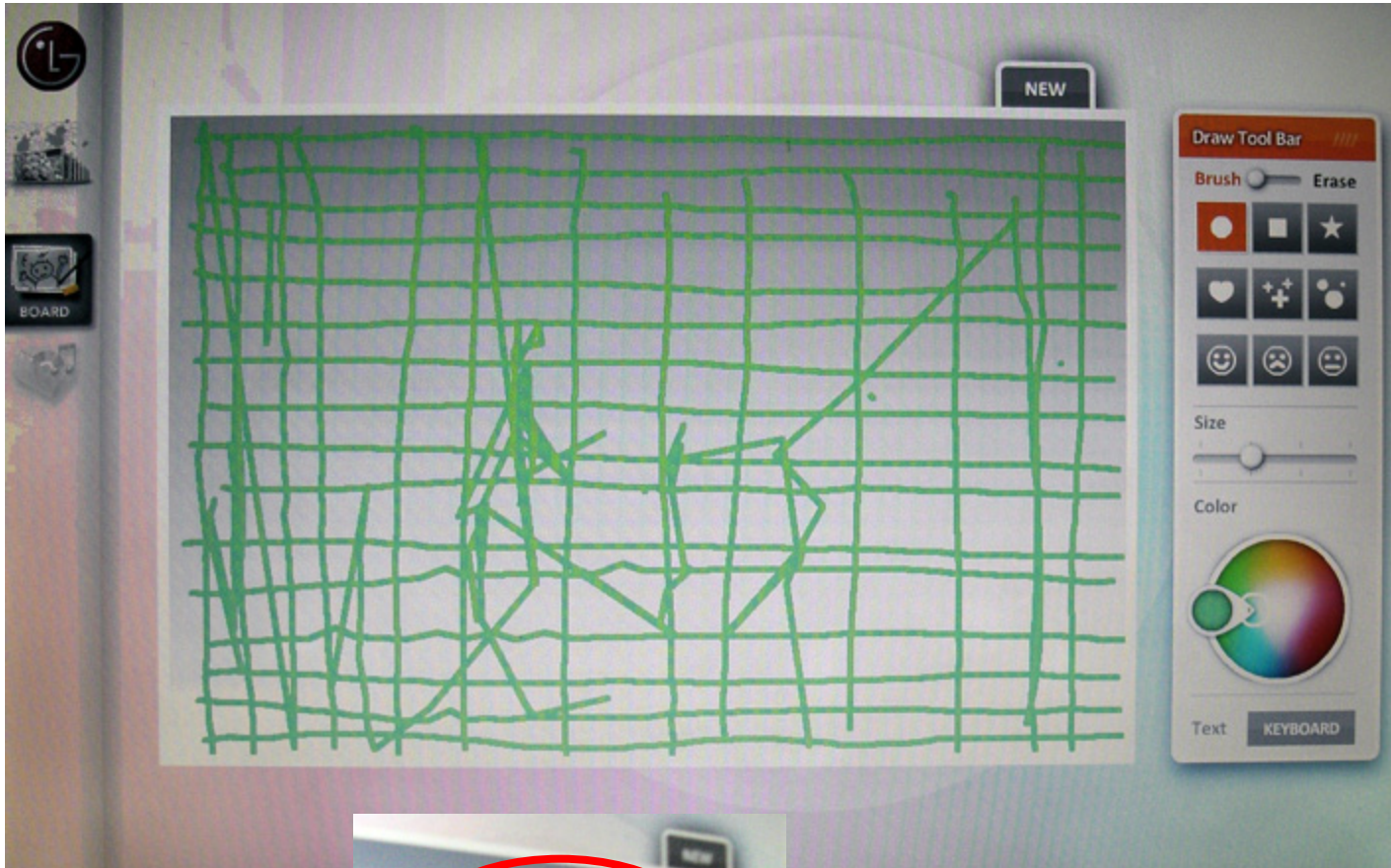
Source: LG Display

Charge-Sensing...10

Photos taken by author at FPD 2008 in Yokohama



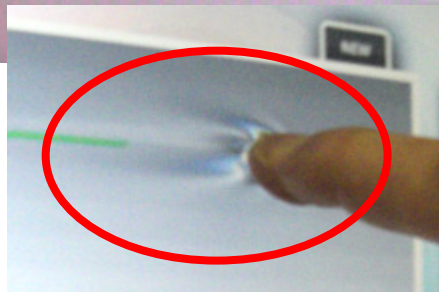
Charge-Sensing...11



**LG Display
13.3" in-cell
capacitive
(SID 2009)**

An attempt to
draw a grid
of straight
lines using a
single finger

Source: Author



Lots of pooling and ink lag!

Charge-Sensing...12

❑ LGD's 13.3" 1280x800 in-cell charge-sensing LCD (10/09)

- ◆ Largest in-cell LCD so far
 - 1 sensor per 4x4 pixels
 - 10 gf activation force
- ◆ Launched at FPD 10/09
- ◆ Win-7 Touch Logo 2/10
- ◆ Positioning
 - High optical quality
 - Sunlight readability (AR?)
 - Preserving thinness
 - Two-touch multi-touch
- ◆ Targeted at notebooks
- ◆ Production in 2H-2010
- ◆ Price-adder for touch function = ??



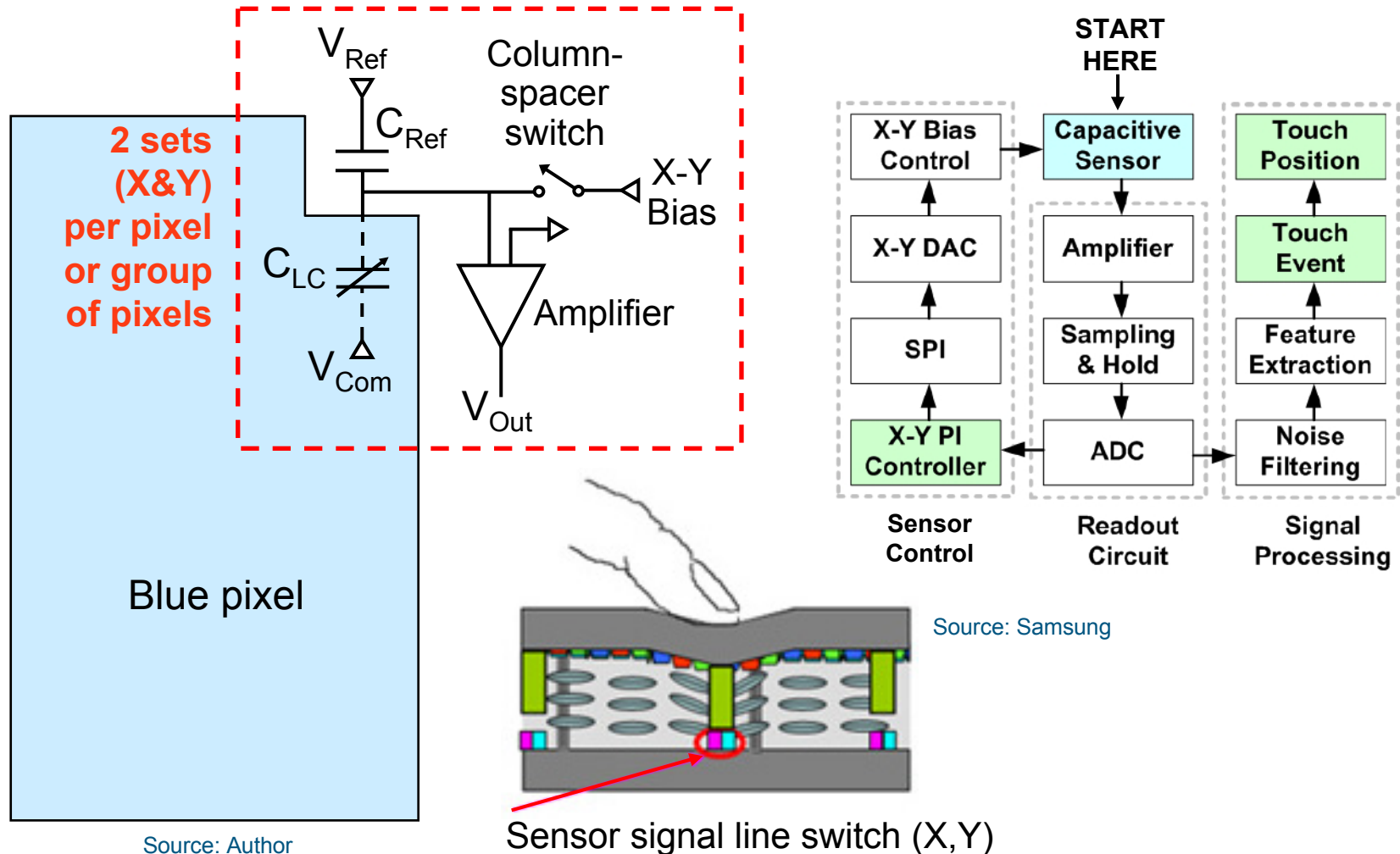
Source: LG Displays



Source: FreakingNews.com

Hybrid Technologies

Samsung hTSP⁽¹⁾...1 (Hybrid Voltage & Charge-Sensing)



Samsung hTSP...2

❑ Principle

✦ Pressing the LCD...

- ❶ Changes changes the dielectric constant of the liquid crystal, which changes the capacitance between the pixel electrodes
- ❷ Closes the column-spacer contacts, which activates the circuit that measures the change in capacitance

❑ Advantages

- ✦ Combining voltage & charge-sensing may make the touch measurement more efficient
- ✦ Using a reference capacitor rather than directly measuring capacitance may make the touch measurement more reliable
 - Or is this done for IP avoidance reasons??

Samsung hTSP...3

❑ Disadvantages

- ✦ Combination of in-cell voltage & charge-sensing disadvantages
 - LCD surface damage (no cover glass)
 - Liquid-crystal pooling
 - Reduced aperture (7%-8% for hTSP)
 - Noise sensitivity
 - Controller horsepower
 - Non-zero touch force
 - Lower resolution

Samsung ST10 Camera...1

First use of any in-cell touch in a commercial product

❑ 3-inch 480x320 (192 ppi) transflective TFT with hTSP hybrid in-cell touch (4/09)

- ◆ One sensor per 8 pixels (60x40 sensing matrix)
- ◆ Works with finger or stylus, but with visible pooling
- ◆ Surface hardness = low
- ◆ Touch-screen includes electrostatic haptic feedback
- ◆ Camera includes MP3, PMP & text-viewer functions



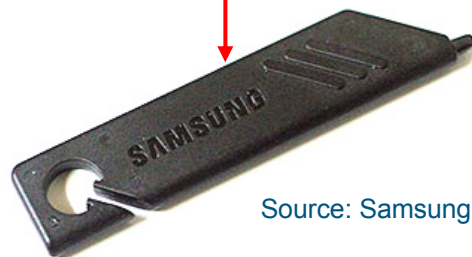
Source: Samsung

Samsung ST10 Camera...2

User-reviewers' comments about LC pooling

- ❑ *"But one thing I feel bad about is that at the moment you touch the screen, it leaves a little after-image on the LCD."*
- ❑ *"It leaves some after-image on LCD when touching. It doesn't affect the image, but it's a little disappointing."*
- ❑ *"It leaves some after-image for 3 sec when touching. At first, it made me embarrassed, but after using it for a day, you can feel there's no problem at all."*
- ❑ *"But it leaves after-image for 2-3 seconds, and in order to prevent this phenomenon, you'd better use touch pen rather than finger."*

Source: Product reviews at www.segadget.com



Source: Samsung

Samsung ST550 Camera (Second-Generation hTSP)

❑ 3.5-inch 800x480 (267 ppi) transflective TFT
with hTSP hybrid in-cell touch (August 2009)

“The touch screen may not recognize your touches correctly when:

- You touch multiple items at the same time
- You use the camera in high-humidity environments
- You use the camera with an LCD protection film or another LCD accessory”



“Do not use other sharp objects, such as pens or pencils, to touch the screen. Doing so may damage the screen.”

“When you touch or drag on the screen, discolorations will occur. It is not a malfunction but a characteristic of the touch screen. Touch or drag lightly to reduce these annoying effects.”

(from the User's Guide)

Source: Samsung



Technology Comparison

Technology Comparison

Characteristic	Light-Sensing	Voltage-Sensing	Charge-Sensing (In-cell)	Hybrid Voltage & Charge	Charge-Sensing (On-cell)
Size limit	20"/unlimited	26"	22"-24"	22"-24"	22"-24"
Touch object	Finger, stylus, light-pen	Finger, stylus	Finger, stylus	Finger, stylus	Finger
Touch force	None	Some	Some	Some	None
Touch resolution	Medium	High	Low	Medium	Low
Cover glass	Yes	No	No	No	Yes
Durability	High with cover-glass	Low	Low	Low	High with cover-glass
True flush surface ("zero bezel")	Yes with cover-glass	No	No	No	Yes with cover-glass
Transmissivity loss	High	Medium	Medium	Medium	Low
External EMI sensitivity	None	None	High	High	High
Internal EMI sensitivity	High	None	High	High	Medium
Ambient light sensitivity	High	None	None	None	None
Flexible substrate	Yes	No	No	No	Yes
Controller complexity	High	Low	Medium	Medium	Medium

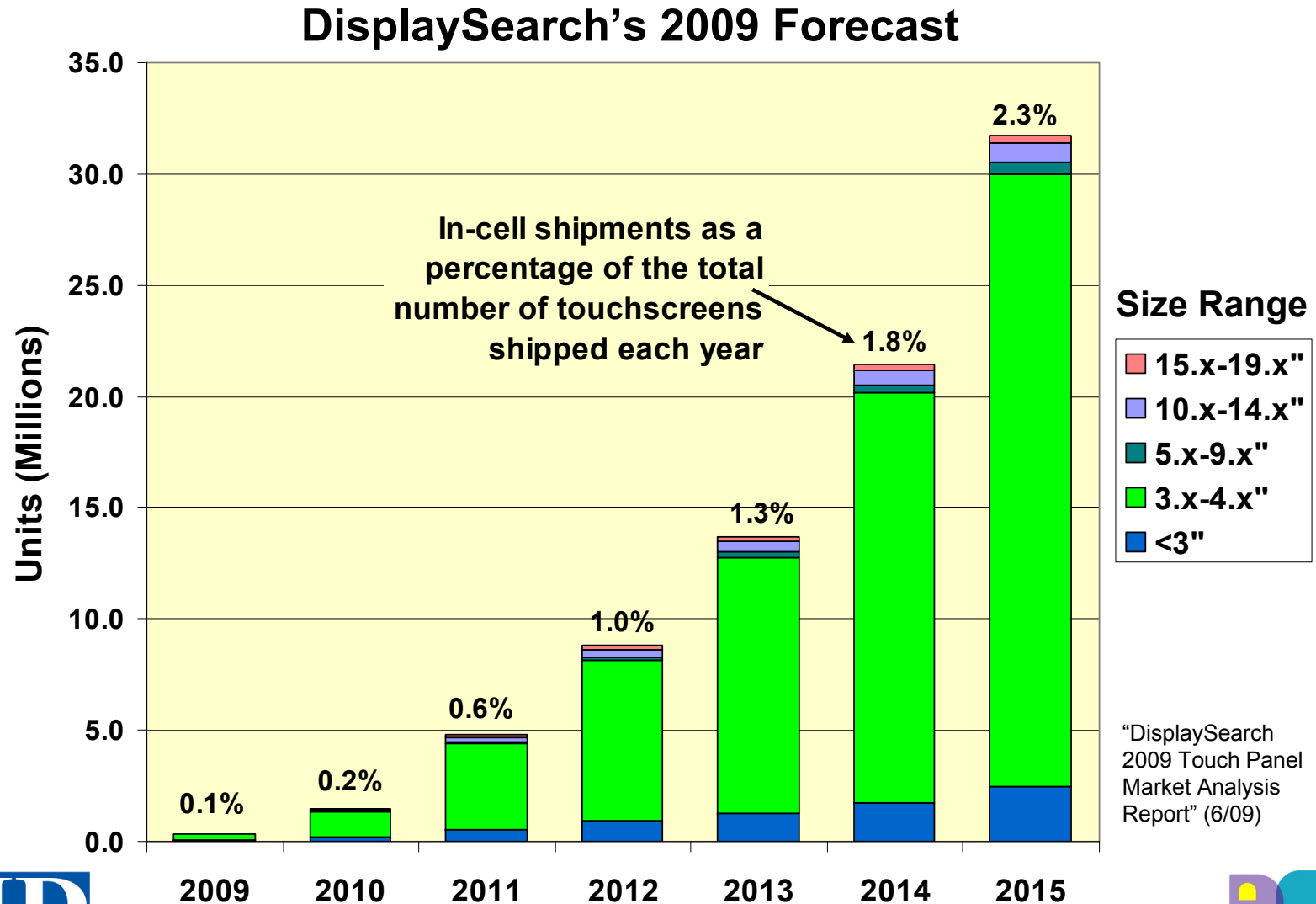
Red-yellow-green color ratings are relative within the in/on-cell technologies, not within all touch technologies. Some values are the author's opinion.



Source: Gizmodo

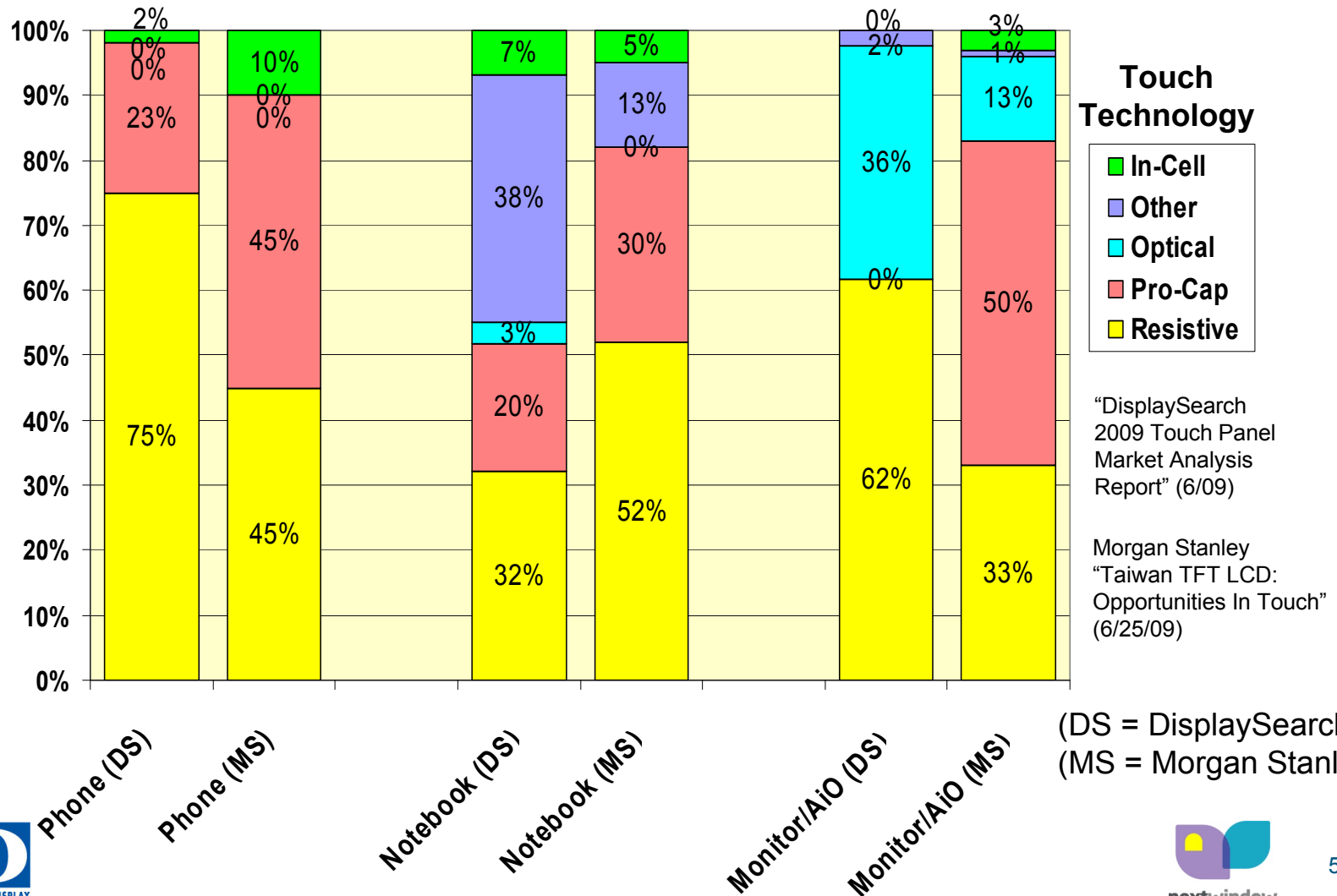
Market Forecasts

LCD In-Cell Forecast by Screen Size



Touch Technology Forecasts for Phones, Notebooks & Monitors/AiOs

DisplaySearch's & Morgan Stanley's Forecast for 2013





Source: CG4TV

Conclusions

Fundamental Issues

❑ LCD design changes

- ✦ Modifying the backplane or frontplane of a single LCD to add in-cell touch costs \$1M-\$2M or more due to masking
- ✦ It is unlikely that LCD manufacturers will make these modifications throughout an entire product line; it will be just in high-volume products with a high demand for touch

❑ OEM second-sourcing

- ✦ Each LCD-maker is defining their own in-cell touch interface which introduces a big new source of potential incompatibility

❑ Choice of touch technology

- ✦ Different applications require different touch technologies; it's almost never “one size fits all” – that's why there are 13 touch technologies!

Status: March 2010

❑ Technologies

- ◆ Light-sensing has the most unresolved problems
- ◆ Voltage-sensing isn't getting any traction
- ◆ Charge-sensing is where all the action is
- ◆ On-cell charge-sensing is easier than in-cell, but it's finger-only
- ◆ Out-cell is the easiest of all

❑ Products

- ◆ One unsuccessful in-cell light-sensing netbook
- ◆ Two successful hybrid in-cell voltage & charge-sensing cameras
- ◆ One newly-launched on-cell charge-sensing OLED mobile phone
- ◆ One in-cell & three on-cell charge-sensing LCDs
- ◆ Almost all the focus is on <10" because >10" is more difficult
and there are no clearly identified high-volume touch applications

Opportunities & Unanswered Questions

❑ Opportunities

- ◆ More durable LCD top surface
 - Harder top polarizer – chicken & egg
- ◆ Eliminating pooling
 - 2-3 years to a low-cost, practical solution?
- ◆ More efficient & powerful controllers
 - Faster, lower power, more multi-touch points
- ◆ Interface standards
 - It's already a problem in the pro-cap world

❑ Unanswered questions

- ◆ Why isn't voltage-sensing getting any traction?
- ◆ Why is so much of what's been done so far at such high dpi?
- ◆ Is the 60 Hz in-cell sampling limit going to become a problem?
- ◆ Is in-cell going to end up being just a 10% niche?

Conclusion

It's still early days!

*In-cell touch still has some distance
to go to reach full commercialization*



Thank You!



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Source: Vissumo

Appendix

Touch Papers & Posters at SID 2010

Technology	Number
Charge-sensing in/on-cell	7
Light-sensing in-cell	6
Optical imaging	2
Multi-touch (digital) resistive	2
Bending wave	1
Simultaneous pen & touch	1
Anti-fingerprint coating	1
Glass for touch-screens	1
CNT as an ITO replacement	1
Piezo-actuated haptics	1
Applying multi-touch	1
Touch history	1
TOTAL	25

There Is No Perfect Touch Technology!

Technology	Major Advantage	Major Flaw
Analog Resistive	Low cost	Low durability
Digital Resistive	Multi-touch	Low durability
Surface Capacitive	Touch sensitivity	High drift
Projected Capacitive	Multi-touch	Finger-only
Surface Acoustic Wave	Durability	Soft touch object
Traditional Infrared	Reliability	High cost
Waveguide Infrared	Low cost	Contamination
Optical	Scalability	Profile height
Acoustic Pulse Recognition	Any touch-object	No touch & hold
Dispersive Signal Technology	Any touch-object	No touch & hold
Force Sensing	3D substrate	Vibration sensitivity
Vision-Based	Multi-touch	Projection only
LCD In-Cell (Light-Sensing)	Integration	Sensitivity
LCD In-Cell (Voltage-Sensing)	Integration	Durability
LCD In-Cell (Charge-Sensing)	Integration	Durability
LCD On-Cell (Charge-Sensing)	Integration	Finger-only